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Experimental and Numerical Study of Fluid Flow, Energy Transport, and Deforming Interfaces in the Electron-Beam Evaporation of Titanium*

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The electron-beam evaporation of titanium alloys is an important step in the formation of metal matrix composites for aircraft components. In a typical process, an electron-beam is used to heat and evaporate alloy from the top of a rod which is pushed from below through a water-cooled crucible. At the beam impingement zone, metal circulates strongly in a pool as a result of buoyancy and capillary forces. The thrust of the departing vapor depresses the liquid-vapor interface. The pool extends to the cold crucible wall where it forms an interface with complex thermal-mechanical characteristics. The performance of this system is strongly influenced by the interaction of flow and heat transfer with these interfaces.

Experiments were performed in which an electron-beam operating in the nominal range of 30-40 kW was used to evaporate pure titanium from the top of a 3 in. diameter rod. Variations were made in the e-beam power, sweep pattern, and sweep frequency. Time-varying evaporation rates were obtained from measurements of the rod length and the absorption of a laser beam by the vapor stream. Temperature rises in the cooling water were used to determine heat flows, and the deformation of the top surface of the pool is revealed in video images from a low-angle camera. The solid-pool interface was obtained from metallographic cross-sections of the metal rod.

A finite element model was developed for this evaporation system which includes the effects of fluid flow and energy transport in the pool and conduction in the solid. The deformation of the liquid-vapor and solid-liquid interfaces are tracked using a mesh which deforms along spines parallel to the rod axis. A comparison is made between the finite element simulations and the measurements.

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